Section 4 -- Freshwater Inflow and Salinity in the Caloosahatchee Estuary

Introduction

Quantifying relationships between freshwater inflow and the spatial and temporal distributions of salinity in the estuary is a critical step in deriving a MFL. This relationship allows calculation of the freshwater inflow required to position the “right salinity in the right place”.

In the initial technical documentation, a statistical regression equation was used to quantify the relationship between discharge at S-79 and salinity in the downstream estuary. Freshwater sources to the Caloosahatchee Estuary include: the Caloosahatchee River at S-79, the Orange River and other tributaries in the tidal basin down stream of S-79, overland runoff, waste water treatment facilities, direct rainfall and ground water seepage. All these additional sources were implicitly included in the regression equation and this has two major consequences.

First, statistical regression models have low precision (**Figure 4-1**). For example, one equation predicted that a 30-day average discharge of 300 cfs would produce a mean salinity of 11.4 ppt at the Ft. Myers Yacht Basin. Accounting for error however the mean salinity could actually range from 5.4 to 17.4 ppt. Wild celery, *Vallisneria americana,* tolerates the mean and lower limit, but not the high limit of this range of variation.

The salinity at Ft. Myers results from a combination of discharge at S-79 and downstream sources in the tidal basin. The salinity produced by a discharge of 300 cfs at S-79 will depend on the magnitude of input from downstream tributaries and ground water. The magnitude of this downstream input will depend on whether antecedent conditions have been wet or dry. While on average a 300 cfs discharge at S-79 has been shown to produce a salinity of about 10 ppt at the Ft. Myers monitoring site, this will not always be the case. Sometimes the actual salinity will be lower and sometimes higher.

The second consequence of relating downstream salinity to discharge at S-79 is that downstream sources remain unquantified. When the discharge at S-79 is 300 cfs, the additional downstream inflow required to produce 10 ppt at Ft. Myers remains unknown.

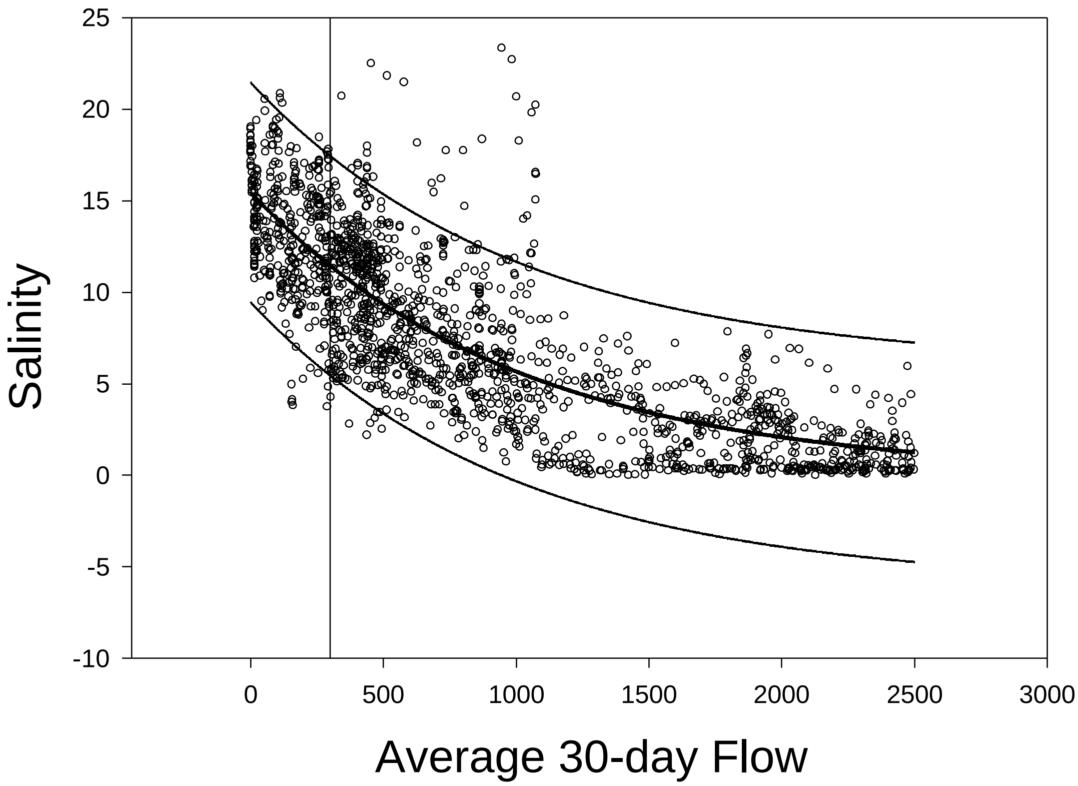


Figure 4-1. Daily average salinity st the Ft. Myers surface salinity sensor as a function of the 30-day average discharge at S-79. Vertical reference line is at 300 cfs. Upper and lower regression lines indicate 95% confidence intervals.

In other words, the total inflow required to produce 10 ppt at Ft. Myers is not known (Total inflow = Inflow at S-79 from basins east of S-79 + downstream sources in the tidal basin west of S-79, **Figure 4-2**).

An alternative and more acceptable approach to statistical regression, is to use a numerical, mass balanced model in which flows from different sources can be specified (Edwards et al. 2000). Thus, the total freshwater inflow required to produce a given salinity in the estuary can be estimated. The contribution of discharge at S-79 and the contribution from downstream tidal basin sources to total inflow can be quantified, compared and contrasted.

Relationship Between Inflows and Salinity

In this section the relationship between freshwater inflow and salinity in the Caloosahatchee Estuary is examined using recently developed modeling tools. The following relationships are evaluated:

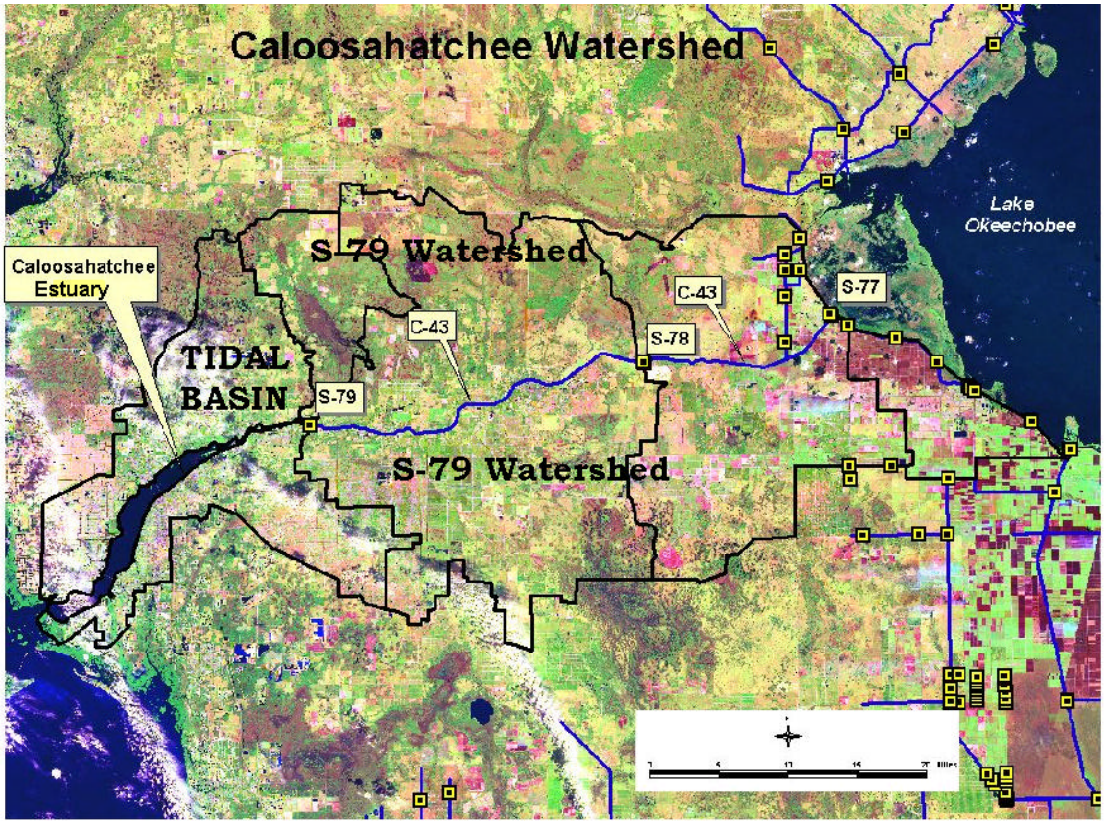


Figure 4-2. Caloosahatchee Watershed showing the Tidal Basin that drains into the estuary west of S-79 and the S-79 Watershed that drains to the estuary through S-79.

- Relationship between total freshwater discharge to the estuary and the distribution of salinity in the estuary. This relationship was derived from a newly developed hydrodynamic model.

- Relationship between tidal basin inflows and inflow at S-79. This relationship answers questions such as: If inflow at S-79 is 800 cfs, what is the inflow from the downstream tidal basin? Until recently, estimates of tidal basin inflow have not been available. However, completion of the Tidal Caloosahatchee Watershed Model (Petersen et al. in review) makes possible the first estimates of tidal basin inflow. Only a three year period of simulation was available to compare tidal basin inflows with inflows at S-79. This period of record was not long enough to make a meaningful comparison. Therefore, an application model was developed to simulate a long-term, rainfall driven period of record for the tidal basin.

- Relationship between present and future inflows and compliance with MFL criteria. The initial technical documentation concluded that the MFL was not now being met and construction of proposed CERP infrastructure facilities, in combination with operational changes and regulatory approaches, was identified in as a component of the recovery strategy. This analysis provides answers to questions such as: How often are MFL criteria now being met and how often will they be met in the future? A rigorous examination of this question requires long-term records of inflows and salinity that include a range of hydrological conditions.

Long-term (31 year) time series of freshwater discharge at S-79 were estimated in two ways: from actual measurements and from rainfall driven regional watershed models. Regional watershed models were used to derive time-series of discharge at S-79 for two scenarios: with and without CERP infrastructure components. Inflows from the tidal basin were estimated from a rainfall driven application model.

The hydrodynamic model was too computationally complex for a 31-year simulation of salinity. Therefore, a less complex regression model, based on short-term results from the hydrodynamic model, was used to estimate salinity. Using the discharge scenarios described above, two 31-year time series of salinity in the estuary were generated -- for present conditions and for future conditions with CERP components in place.

Present and Future Discharge at S-79

Time series of present and future discharge at S-79 were generated from existing measured data and from regional watershed models. Measured inflows at S-79, referred to as the “Historic Case”, cover the period from 1965 to 1995 and includes changes in discharge attributable to changes in land use. Present conditions were assessed by employing the so called CERP ‘1995 Base’ scenario. Using a regional watershed model, the time-series of rainfall for the 31-year period 1965-1995 was applied to generate a time-series of discharge at S-79. The model uses 1995 land use and thus controls for changes in runoff caused by temporal changes in land use during the 31-year period. This modeled time-series of discharge has served as an estimator of current hydrologic conditions through out the CERP process (USACE and SFWMD 1999).

A conclusion of the initial technical documentation supporting the Caloosahatchee MFL was that the MFL could not be met under current conditions. A recovery and prevention strategy was therefore required by Section 373.042(1) F.S. and was described for the Caloosahatchee River in Section 40E-8.421. The recovery plan includes operational, regulatory (Consumptive Use Permitting and Water Shortage Policy) and structural components. The structural components for recovery of the Caloosahatchee MFL depend on implementing key CERP water storage projects in the C-43 basin. These projects, which include reservoirs and aquifer storage and recovery wells (**Appendix E**), will help attenuate extreme flows to the estuary by reducing the surface water runoff 'peaks' during high flow events and providing supplemental flows during drier times.

To evaluate this recovery strategy, a long-term 31-year times-series of discharge at S-79 was generated using the same regional modeling approach as before, except that reservoirs and ASR facilities were included. This is termed the '2020 with Restudy Components' scenario and shows conditions in 2020 after the proposed water management facilities are constructed. The '2020 with Restudy Components' models these components as conceived in the initial CERP documents. These components are being refined as part of the process for development of the CERP C-43 Project Implementation Report. No refined hydrology is yet available.

Inflow from the Tidal Basin

The '1995 Base' and '2020 with Restudy' scenarios present estimates of discharge at S-79 (including regulatory releases from Lake Okeechobee). They do not estimate total inflow to the Caloosahatchee Estuary. Additional sources of inflow exist downstream (west) of S-79 in the Tidal Basin surrounding the Caloosahatchee Estuary. Until recently, there has been a lack of measured or modeled inflows from the downstream tidal basin. However, the completion of the Tidal Caloosahatchee Watershed Model (Petersen et al. in review) makes possible the first estimates of tidal basin inflow to the Caloosahatchee Estuary (**Appendix G**). The Tidal Caloosahatchee Basin Model (Petersen et al. in review) is an application of the MikeShe code. The model is a fully coupled, surface water and groundwater model intended to accurately simulate all significant hydrologic processes in the watershed including evaporation, runoff, stormwater detention, river hydraulics, stream water management, groundwater withdrawals and recharge, etc. Through contract (Petersen and Copp, 2002) a special three year (1998-2000) simulation examining the spatial distribution of inflows from the tidal basin to the estuary was obtained (**Appendix G**).

While instructive, the period of record (three years) from the Tidal Caloosahatchee Basin Model was not sufficient to assess the relationship between discharge at S-79 and total inflow to the estuary under a variety of hydrologic conditions. The record was also not sufficient to generate the 31-year period of record needed to examine compliance with MFL criteria. Therefore an application model was developed. A rainfall driven application model based on linear reservoir theory was developed to estimate inflow from the downstream tidal basin (**Appendix G**). This reservoir model was calibrated to the 3 years of output from the Tidal Caloosahatchee MikeShe model (**Figure 4-3**). Time-series of total inflow were created by combining estimates of downstream tidal basin inflows generated from the reservoir model with the two time-series (1995-Base, 2020 with Restudy Components) of discharge from the upstream watershed at S-79.

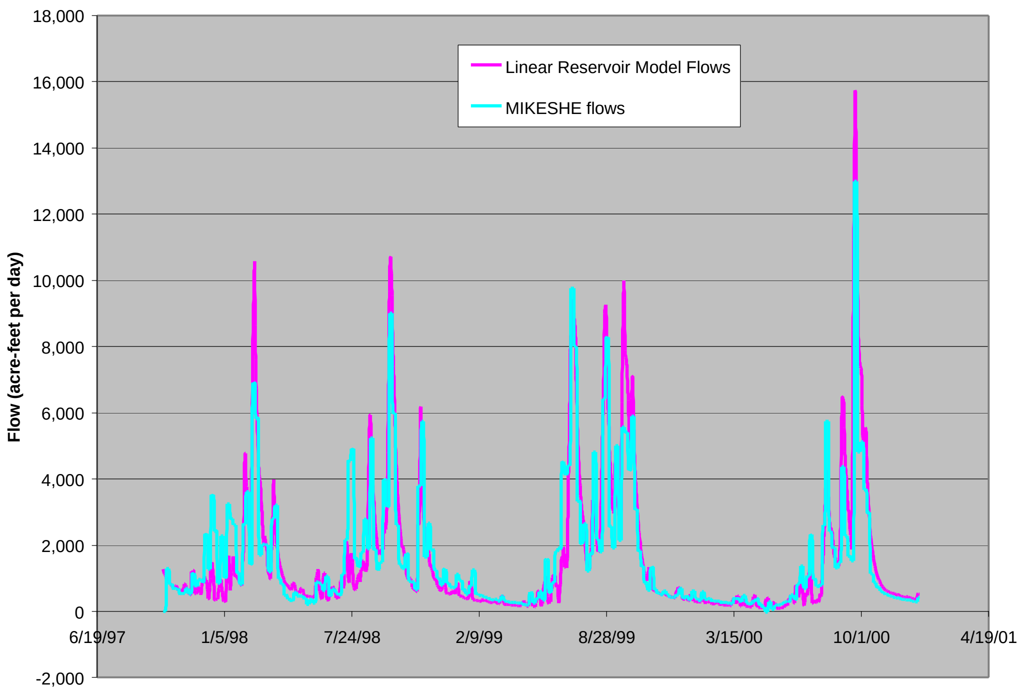


Figure 4-3. Comparison of 5-day flows: MikeShe Model for the Tidal Caloosahatchee

Estuarine Hydrodynamic Model

During the past year District Staff have been used the CH3D software to develop a numerical model (**Appendix F**). CH3D is a three-dimensional model with a curvilinear-grid that simulates time-dependent circulation in estuaries, lakes, and coastal waters. For the present application to an estuarine system, the model estimates the following hydrodynamic variables: surface elevation, 3-D velocities, salinity, and density.

The salinity model for the Caloosahatchee Estuary (**Appendix F**) was excerpted from a larger CH3D Charlotte Harbor model (Sheng, 2001). The larger Charlotte Harbor model was calibrated using data collected during the summer of 1986 at 6 stations located in Pine Island Sound and near the Peace River. The hydrodynamic model was calibrated with 2 months of data, while the salinity model was calibrated with 2 weeks of data. The Caloosahatchee and San Carlos Bay portions of the model were not calibrated by Sheng (2001). District staff calibrated the Caloosahatchee Estuary portion of the model using a 2.5 months period of data, collected every 15 minutes at five stations (**Figure 4-4**). During this period (October 15 to December 31, 2000), salinity rose from approximately 5 ppt to 20 ppt at Ft. Myers (**Figure 4-5**).

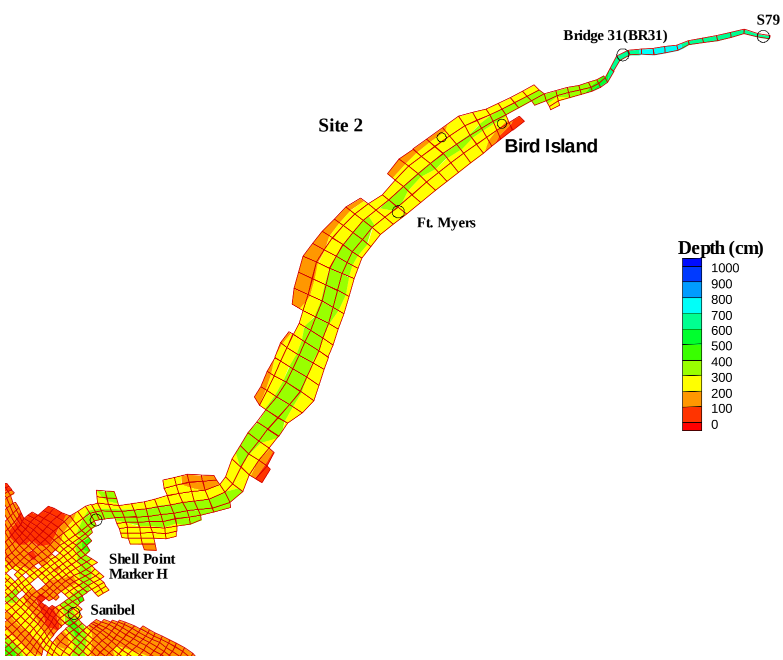


Figure 4-4. Bathymetry of the Caloosahatchee Estuary and location of monitoring stations. Salinity monitoring stations: S79, Bridge 31 (BR31), Ft. Myers, Shell Point (MarkerH) and Sanibel; Wild Celery, *Vallisneria americana*, monitoring stations: Bird Island and Site 2.

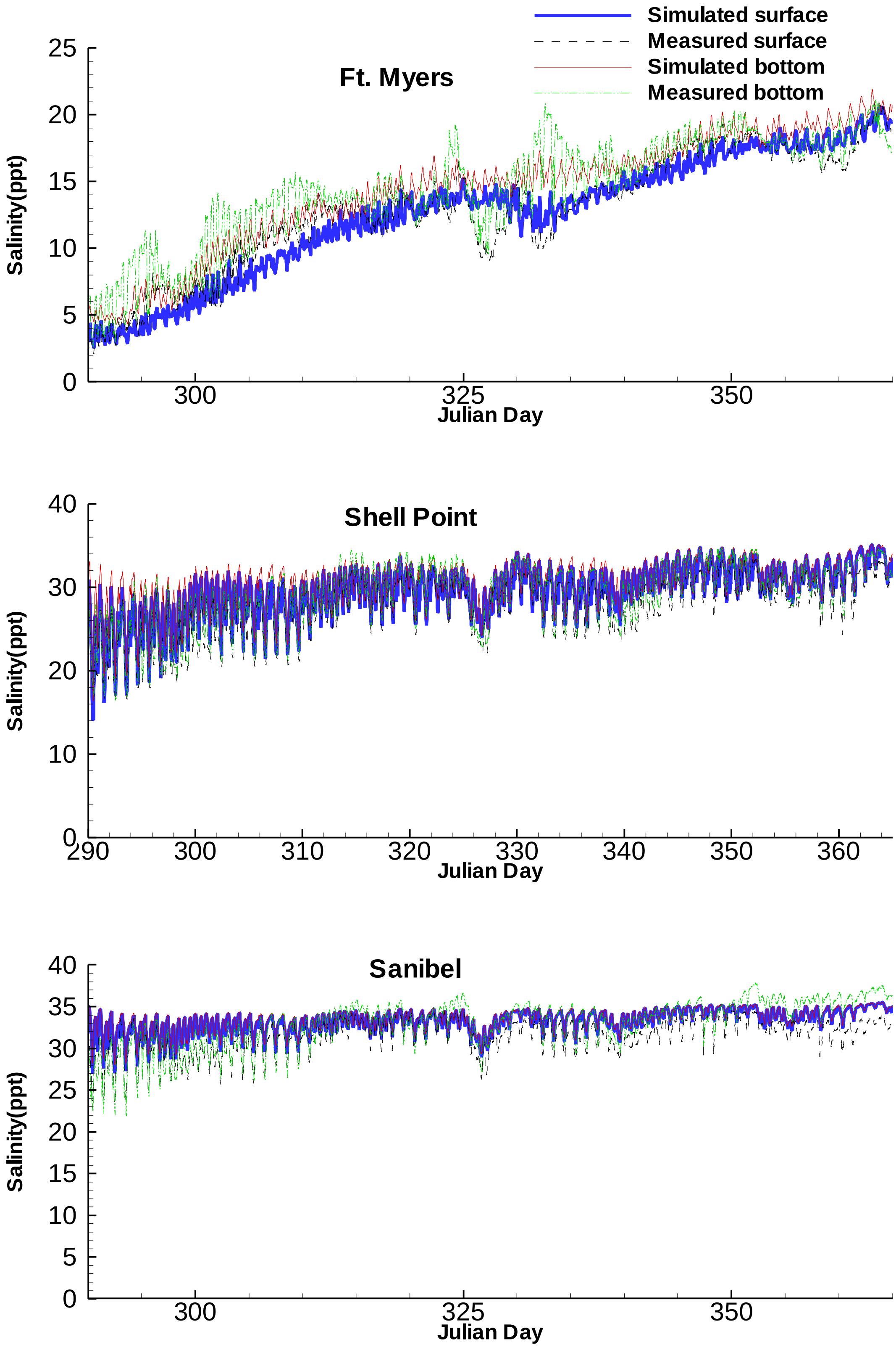


Figure 4-5 Salinity calibration at Ft. Myers, Shell Point and Sanibel.

The initial calibration of the model was driven by freshwater discharge at S-79, tide, wind, direct rainfall, and evaporation. For the initial model formulation and calibration, the total freshwater inflow to the estuary, including inflow from downstream tributaries, ground water, and other downstream sources were assumed to enter at S-79.

Freshwater Inflow and Salinity

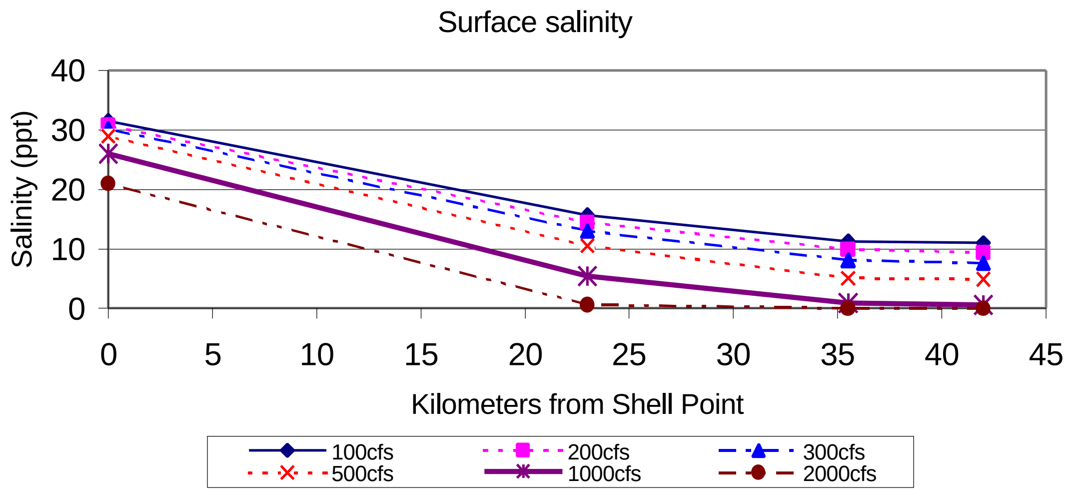
Using the CH3D hydrodynamic model, a group of curves describing the relationship between **total inflow** and the spatial distribution of salinity in the estuary were generated. Eight (8) scenarios (discharges at 50 cfs, 100cfs, 200cfs, 300cfs, 500cfs, 1000cfs, 1500 cfs and 2000cfs) were simulated for 40 days. Forty-day simulations allowed the model to reach equilibrium conditions. The last 10 days of the 40 days simulation results were averaged to obtain the salinity at four locations: S-79 (42 km), BR31 (36 km) , Ft. Myers (23 km) and Shell Point (0 km)(**Figure 4-6**). A **total inflow** of 500 cfs produces a salinity of about 10 ppt at Ft. Myers (23 km) (**Figure 4-6**).

Partitioning Total Flow

Total inflow is a combination of discharge at S-79 from the upstream watershed east of S-79 and inflow from downstream sources in the tidal basin. Both sources need to be quantified in order to establish a minimum flow at S-79 that meets the downstream salinity criteria.

Time-series of total inflow were created by combining estimates of downstream tidal basin inflows with the three time-series (Historic Case, 1995-Base, 2020 with Restudy Components) of discharge from the watershed upstream of S-79. Downstream tidal basin flows were generated from the reservoir model.

The frequency distributions of total monthly flows for both the ‘Historic Case’ and the ‘1995 Base’ conditions are heavily skewed towards low flows < 325 cfs (**Table 4-1**, **Figure 4-7**). In both cases, there is a secondary peak of higher flows in the 1500 – 4500 cfs range. Under the ‘2020 with Restudy’ scenario the percentage of both low and high flows is diminished. This results in a frequency distribution of total monthly flows with a single maximum in the 500 to 800 cfs range (**Table 4-1**, **Figure 4-7**).



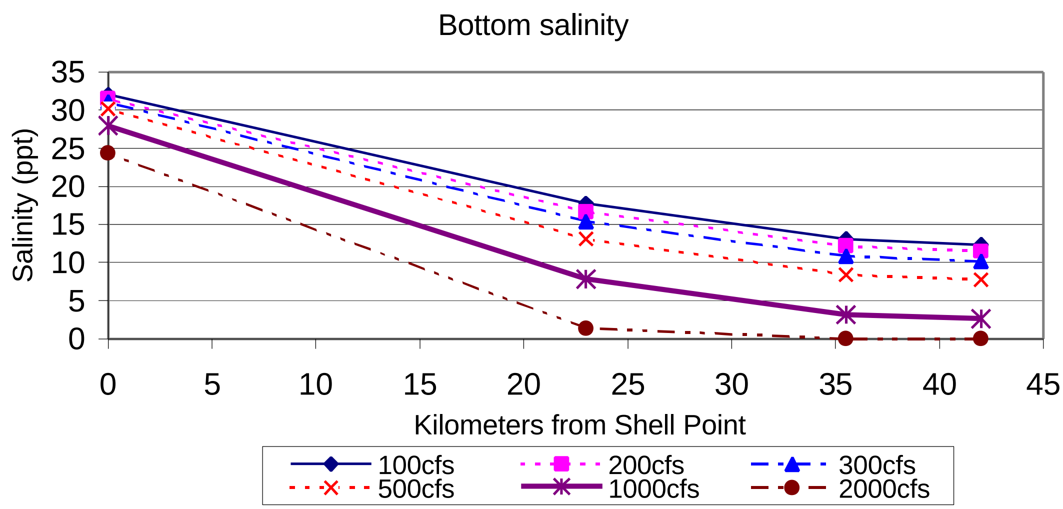


Figure 4-6. Results of Hydrodynamic Model. Salinity as a Function of Total Freshwater Inflow to the Caloosahatchee Estuary.

Table 4-1. Frequency Distribution of Total Estuary Inflows (see also **Figure 4-7**).

	Probability of Monthly Flows within Flow Range		
Flow Range	**Historic**	**1995 Base**	**2020 with Restudy Components**
<325 cfs	23%	32%	2%
325 to 500 cfs	9%	9%	16%
500 to 800 cfs	12%	6%	32%
800 to 1500 cfs	13%	12%	25%
1500 to 2800 cfs	17%	13%	10%
2800 to 4500 cfs	11%	14%	9%
4500 to 8000 cfs	11%	9%	4%
>8000 cfs	4%	4%	1%

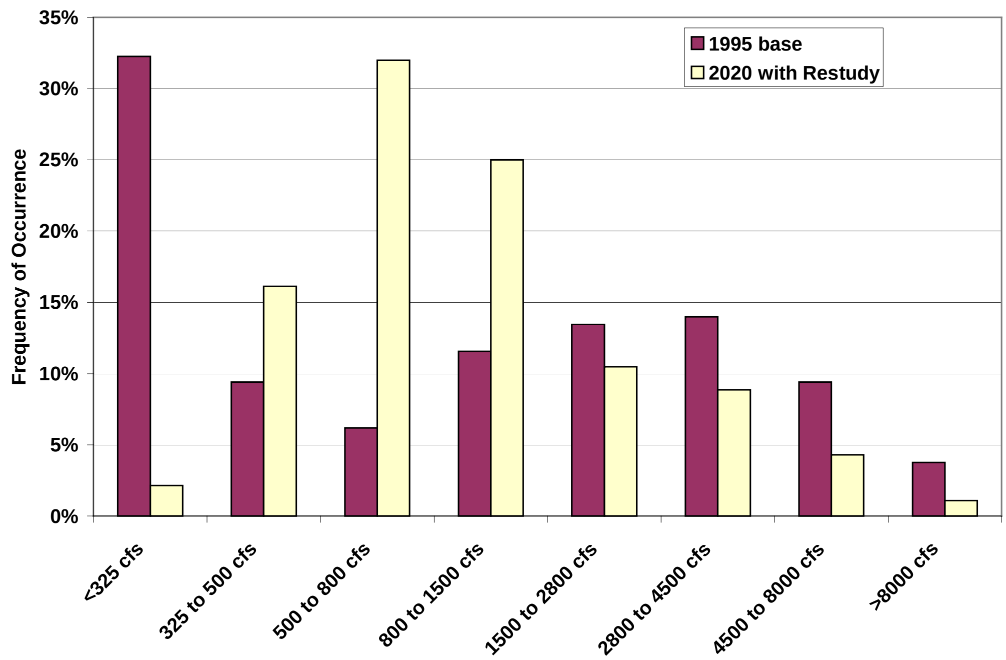


Figure 4-7. Distribution of Average Monthly Caloosahatchee Estuary Inflows – 1965 to 1995. Inflows include Upper Basins, Tidal Basin, and Lake Okeechobee regulatory releases

The new information on tidal basin inflows places the MFL flow criterion of 300 cfs at S-79 in the context of total inflow to the estuary. **Table 4-2** indicates that under present conditions ('1995 Base'), when discharge at S-79 is about 300 cfs, total inflow to the estuary is above 500 cfs about half the time (57%) and below 500 cfs about half the time (43 %). This proportionality also holds for the 'Historic Case' (**Table 4-2**).

Table 4-2. Evaluating watershed inflows when S-79 monthly flows are near 300 cfs (275 to 325 cfs)

	Probability total flow in range (cfs)		
Total Flow	**Historic**	**95base**	**2020 with Restudy Components**
<325 cfs	7%	0%	13%
325 to 500 cfs	53%	43%	68%
500 to 800 cfs	33%	43%	20%
800 to 1500 cfs	7%	14%	0%
1500 to 2800 cfs	0%	0%	0%
2800 to 4500 cfs	0%	0%	0%
4500 to 8000 cfs	0%	0%	0%
>8000 cfs	0%	0%	0%
months is in range	15	14	40

Under current conditions, a mean monthly discharge of 300 cfs at S-79 would be expected to produce an average salinity of about 10 ppt. About half the time salinity would be less than 10 ppt and about half the time greater. This partitioning of inflows, in part, explains the results of the original regression analysis: on average a discharge of 300 cfs at S-79 produces a salinity of about 10 $^{o}/_{oo}$ at Ft. Myers (**Figure 3-1**).

The relationship between S-79 flows of 300 cfs and total flows of 500 cfs changes under the '2020 with Restudy Components' scenario. Under this scenario, when S-79 flows are near 300 cfs, total flows are below 500 cfs most of the time (80%) and are in the range between 500 cfs and 800 cfs only 20% of the time (**Table 4-2**).

It is not surprising that the correlation of S-79 flows and total flows changes in the 2020 scenario; reservoirs and ASRs upstream of S-79 are designed to deliver base flows to the estuary. This shifting of sources is demonstrated in **Figure 4-8**, which shows the contribution of upper basin flow as a percentage of total estuary inflow for both '1995 Base' and '2020 with Restudy' scenarios. Under the '1995 Base' conditions, upper basins contribute 42% of flows in the 325 cfs - 500 cfs range and 62% of flows in the 500 cfs – 800 cfs range. Under '2020 with Restudy' conditions, upper basins contribute 78% of flows in the 325 cfs - 500 cfs range and 70% of flows in the 500 cfs – 800 cfs range.

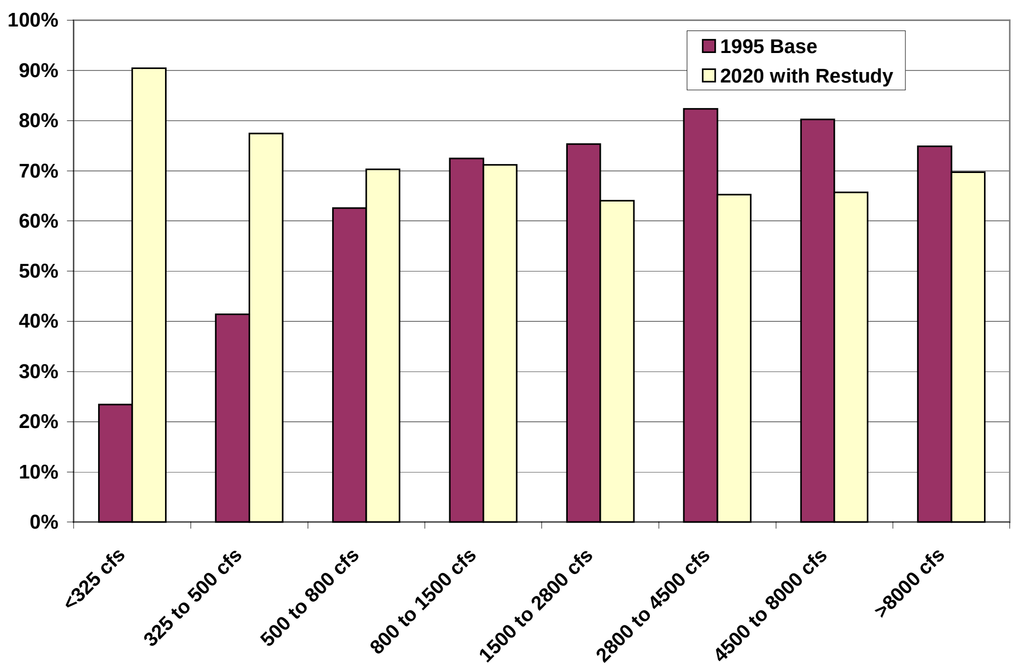


Figure 4-8. Percentage of Average Monthly Caloosahatchee Estuary Inflows contributed by Upper Basins.

Many of these 300 cfs flows are delivered at S-79 from CERP components during dry times when downstream tidal inflows are probably low and provide little augmentation. Under present conditions, we may also expect that releases of 300 cfs at S-79 from Lake Okeechobee will not correspond to a total inflow of 500 cfs to the estuary if these releases are made during drier periods.

Evaluation of MFL Salinity Criteria:

The Caloosahatchee MFL rule states that: "A MFL exceedance occurs during a 365 day period, when a) a 30-day average salinity concentration exceeds 10 parts per thousand at the Ft. Myers salinity station . . . or (b) a single daily average salinity exceeds a concentration of 20 parts per thousand at the Ft. Myers salinity station. Exceedance of either subsection (a) or subsection (b), for two consecutive years is a violation."

As indicated earlier, one purpose of this review is to ascertain the extent to which MFL salinity criteria are presently being met and the extent to which they will be satisfied in the future. Evaluation of the '1995 Base' and '2020 with Restudy' scenarios constitutes a viable method. Evaluation of the 'Historic Case' is another method, and both will be employed here.

Due to computer hardware constraints, the estuarine hydrodynamic model could not produce a 31-year simulation of salinity. To estimate long term salinity patterns in the estuary, a regression model was derived from the equilibrium relationships between fresh water inflow and salinity in the estuary shown earlier. The regression model was calibrated with a 10-year period of salinity records at Bridge 31 (BR31) and Ft. Myers, as well as a 6-month record at Bird Island (**Appendix F**). The time series of total inflow generated above (1995 base discharge or 2020 Restudy at S-79 + tidal basin inflow) was used to generated 31 years of salinity at various locations in the estuary. The SFWMD has been monitoring salinity at Ft. Myers since 1992. The period of record for daily average salinity and 30-day moving average salinity appears in **Figure 4-9**. During the eleven year period for Jan 1992 to March 2002, the 10 ppt moving average criterion was exceeded in 9 of 11 years (no exceedances in 1995 and 1998). At no time was the single daily average 20 ppt criterion exceeded before the 10 ppt criterion. It should be noted that during the period from January to March of 2001, salinity was greater than 20 ppt for a

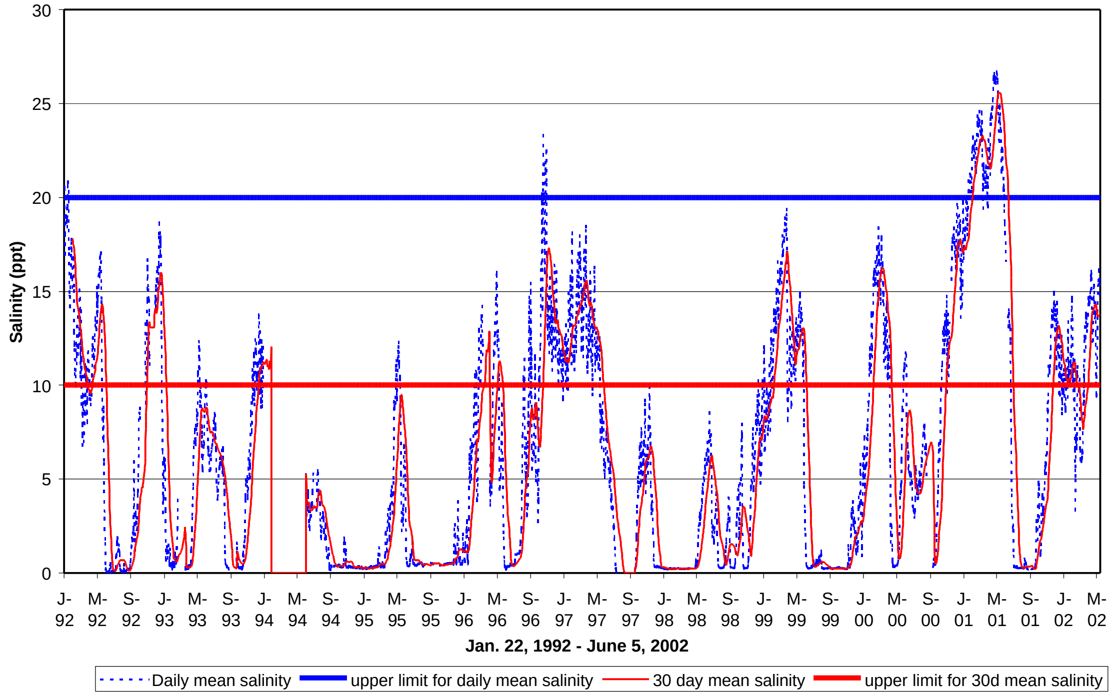


Figure 4-9. Salinity at Ft. Myers Yacht Basin and Exceedance limits for the Caloosahatchee Minimum Flow and Level. Period of record is January 1992 to March 2002.

duration that exceeded the 30-day moving average. These were the lowest flow conditions that occurred during the 10-year period of record, resulting in a major grass die-off. The *V. americana* community has not yet recovered from this event. Results of the 31-year '1995 Base' and '2020 with Restudy' simulations of estuarine salinity are shown in **Figure 4-10.** The 30-day moving average salinity at Ft. Myers exceeded 10 ppt in every year modeled for both simulations.

Nevertheless, **Figure 4-10** demonstrates a marked reduction in 30-day moving average salinity when CERP components are in place. However, this reduction is not quite enough to influence the predicted rate of exceedance (**Table 4-3**). While the percent of time that the 30-day moving average stays above 10 ppt is nearly the same for both scenarios (~50 %), the mean is closer to 10 ppt in the '2020 with Restudy' scenario -- within the 10–13 ppt range for 38 % of the time compared to 12 % for the '1995 Base.'

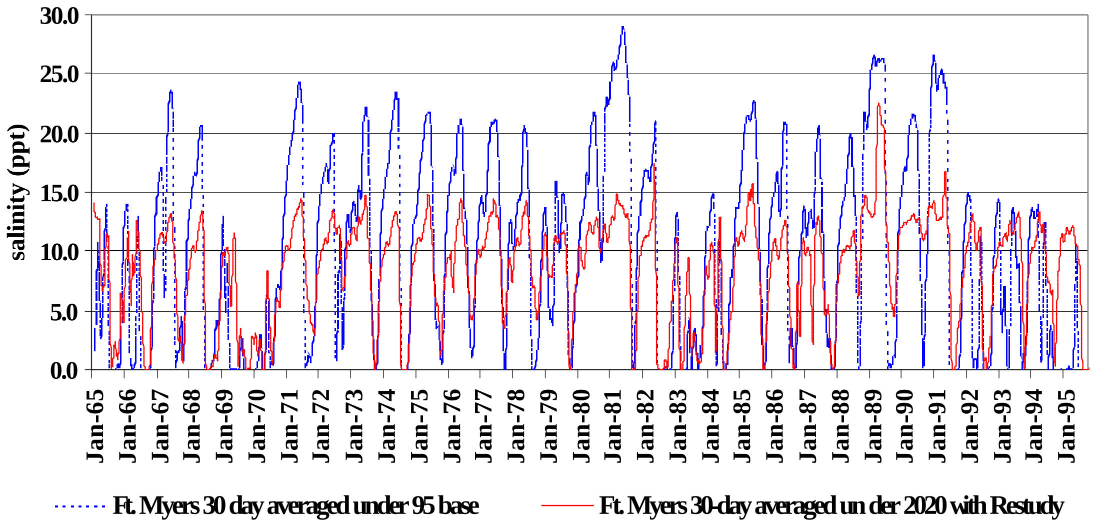


Figure 4-10. Results of the 31-year '1995 Base' and '2020 with Restudy' simulations of estuarine salinity.

Table 4-3. Predicted salinity at the Ft. Myers Yacht Basin (see Figure 4.2) for the '1995 Base' and '2020 Restudy' scenarios.

Ft. Myers salinity (ppt)	95 base		2020 with Restudy	
	daily (%)	30 day moving average (%)	daily (%)	30 day moving average (%)
0~5	37.9	36.7	25.3	24.5
5~10	8.6	12.0	25.1	27.2
10~13	12.5	11.7	39.1	37.6
13~15	12.5	10.9	8.3	9.2
15~20	11.6	13.9	1.3	0.8
20~25	13.4	11.2	0.9	0.7

Summary

A number of different modeling approaches were used, in conjunction with historical data, to estimate the effects of freshwater flow on salinity conditions in the Caloosahatchee Estuary. Some of these models are still under development and have not been fully verified or calibrated. Preliminary results from these analyses indicate that downstream tidal basin inflows may be an important supplement to flows at S-79. Under current conditions, for 300 cfs released at S-79 to produce 10 ppt at Ft. Myers an additional 200 cfs (total = 500 cfs) may be required from downstream tidal basin inflows. Under current conditions ('1995 Base'), the 300 cfs flow at S-79 is on average associated with a total estuary inflow of 500 cfs; correlating to total flows below 500 cfs 43% of the time and to total flows above 500 cfs 57% of the time. Under the ‘2020 with Restudy’ scenario 300 cfs flows at S-79 correlate to total flows above 500 cfs only 20% of the time. Therefore, a delivery of 300 cfs at S-79, under ‘2020 with Restudy’, is less likely to produce 10 ppt at Ft. Myers. Overall, salinity conditions in the downstream estuary do improve with the addition of CERP infrastructure because the frequency of total inflows <500 cfs decreases from 40% in ‘1995 Base’ to 20% in ‘2020 with Restudy’.

These results suggest that whereas CERP projects provide significant benefits to the estuary in terms of providing freshwater flow during dry periods, even more freshwater flows may be necessary to protect the *V. americana* community from significant harm. Before decisions are made to modify CERP projects or the MFL criteria, however, the models need to be completed and fully calibrated and more sophisticated ways of measuring the flows, especially downstream tidal basin inflows, need to be considered.